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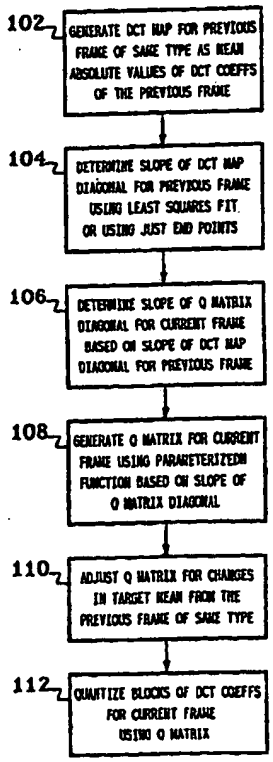
(54) Title: PARAMETERIZED QUANTIZATION MATRIX ADAPTATION FOR VIDEO ENCODING

(57) Abstract

In a video compression processing, such as MPEG–2 compression processing, the quantization (Q) matrix used to quantize discrete cosine transform (DCT) coefficients is updated from frame to frame based on a parameterized Q matrix adaptation algorithm. According to the algorithm, the Q matrix for the current frame is generated based on DCT coefficient data (108) from the previous encoded frame of the same type (e.g., I, P, or B) as the current frame. In particular, the Q matrix is generated using a function based on shape parameters (e.g., the slope of the diagonal of the Q matrix and/or the convexity of the diagonal of the Q matrix), where the diagonal slope for the Q matrix of the current frame is generated based on the diagonal slope of a DCT map (106) for the previously encoded frame. Before using the generated Q matrix to quantize the DCT coefficients for the current frame, the Q matrix is preferably adjusted for changes in the target mean from the previously encoded frame to the current frame.



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PARAMETERIZED QUANTIZATION MATRIX ADAPTATION FOR VIDEO ENCODING

This invention was made with United States Government support under Contract No. 70NANB5H1178 awarded by the National Institute of Standards and Technology. The United States Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to video compression and decompression algorithms.

Cross-Reference to Related Applications

This application claims the benefit of the filing date of U.S. provisional application no. 60/103,119, filed on 10/05/98 as attorney docket no. SAR 13052P.

Description of the Related Art

In a typical transform-based video compression algorithm, such as one conforming to the Moving Picture Experts Group (MPEG) family of algorithms, a block-based transform, such as a discrete cosine transform (DCT), is applied to blocks of image data corresponding either to pixel values or pixel differences generated, for example, based on a motion-compensated inter-frame differencing scheme. The resulting transform coefficients for each block are then typically quantized for subsequent encoding (e.g., run-length encoding followed by variable-length encoding) to generate an encoded video bitstream.

Depending on the particular video compression algorithm, images may be designated as the following different types of frames for compression processing:

- An intra (I) frame which is encoded using only intra-frame compression techniques,
- A predicted (P) frame which is encoded using inter-frame compression techniques based on a reference frame corresponding to a previous I or P frame, and which can itself be used to generate a reference frame for encoding one or more other frames, and

o A bi-directional (B) frame which is encoded using inter-frame compression techniques based on either (i) forward, (ii) reverse, or (iii) bi-directional prediction from either (i) a previous I or P frame, (ii) a subsequent I or P frame, or (iii) a combination of both, respectively, and which cannot itself be used to encode another frame.

Note that, in P and B frames, one or more blocks of image data may be encoded using intra-frame compression techniques.

In MPEG-2 encoding, an (8x8) quantization (Q) matrix can be defined (and updated) for each video frame, where each element in the Q matrix corresponds to a different corresponding DCT coefficient resulting from applying an (8x8) DCT transform to a block of pixel values or pixel differences. For a given frame, the elements in the defined Q matrix are scaled by a quantization parameter (mquant), which can vary from block to block within the frame, to generate quantizer values used to quantize the different blocks of DCT coefficients for that frame.

SUMMARY OF THE INVENTION

The present invention is directed to a parameterized adaptation algorithm for updating the quantization matrix used during video compression, such as MPEG-2 compression. In a preferred embodiment, the parameterized Q matrix adaptation algorithm of the present invention is a real-time vision-optimized encoding (VOE) algorithm that does not require on-line computation of a visual discrimination model (VDM). The VOE element of this algorithm is that, in addition to other parameters of the algorithm, the functional relationship between the DCT statistics and the matrix parameterization is optimized based on the VDM, which can be any perceptual quality metric, using an exhaustive search.

According to embodiments of the present invention, the Q matrix is adapted based on the DCT statistics of the previously encoded frame of the same picture type. The DCT statistics are based on the slope of the main diagonal of the DCT map, which is averaged over a frame. The slope of the parameterized Q matrix is roughly inversely proportional to the slope of the main diagonal of the DCT map. The parameterization of the Q matrix may consist of three parameters: the slope of the matrix along the diagonal, the convexity of the matrix along the diagonal, and a specified constant offset. In one implementation

of the present invention, the slope is updated for each frame type (i.e., I, P, and B frames), and the convexity is fixed to a constant. Another aspect of the algorithm is the mean adjustment of the matrix. Whenever the slope of a matrix changes (i.e., from frame to frame), the effective mean of the matrix should be changed, where the effective mean is preferably kept constant for a given frame.

According to one embodiment, the present invention is a method for processing a current frame of video data, comprising the steps of (a) generating a transform map for a previously encoded frame of video data of the same type as the current frame; (b) generating one or more quantization (Q) matrix shape parameters using the transform map for the previously encoded frame; (c) generating a Q matrix for the current frame using a parameterized function based on the one or more Q matrix shape parameters; (d) quantizing transform coefficients corresponding to the current frame based on the Q matrix; and (e) generating part of an encoded video bitstream based on the quantized transform coefficients.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and advantages of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which Fig. 1 shows a flow diagram of processing for a current frame of video data, according to one embodiment of the present invention.

DETAILED DESCRIPTION

The present invention comprises two parts: (1) the shape adaptation of the quantization matrix and (2) the mean adjustment of the Q matrix. In the first part, the shape (e.g., diagonal slope and convexity) of a Q matrix is determined from the DCT map statistics of the previously encoded frame of the same type. The second part deals with the mean adjustment of the Q matrix after the matrix is updated by the first part of the algorithm. The actual bit rate for each frame is affected by the change in the shape of a matrix. This change is compensated by the mean adjustment algorithm in order to maintain relatively constant bit rate.

Q Matrix Shape Adaptation

Since there are 64 elements in an (8x8) Q matrix and since each 8-bit element can have one of 256 different values, there are 256^{64} different possible Q matrices. In order to reduce the search complexity, the present invention uses a parameterized approach to limit the search to a relatively small number of classes of matrices. In one embodiment, this parameterized approach relies on three parameters: the slope of the Q matrix along the diagonal, the convexity of the Q matrix along the diagonal, and a specified constant offset.

One possible parameterization is based on a sinusoidal function, as represented in Equation (1) as follows:

$$q[i][j] = a*(r-ctr) + b*(\sin(4*pi/end) - 2/pi) + c \quad (1)$$

where:

q[i][j] is the element at row i and column j of the Q matrix, wherein i,j = 0,...,7;

a is the slope of Q matrix diagonal;

ctr is a constant equal to 7/sqrt(2);

b is the convexity of the Q matrix diagonal;

end is a constant equal to 7*sqrt(2); and

c is the specified constant offset.

Another possible parameterization is based on rational functions, as represented by Equation (2) as follows:

$$q[i][j] = (a / sqrt(2) * (i+j+7)) + b*diagconvex(i,j) + d*crossconvex(i,j) + c \quad (2)$$

where:

diagconvex is a function that determines the convexity along the diagonal direction;

crossconvex is a function for the convexity along the cross-diagonal direction; and

d is the convexity along the cross diagonal.

In one implementation, when i-j ≥ 0, the diagonal convexity function is given according to Equation (3) as follows:

$$\text{diagconvex}(i,j) = 20/7 * (7-i)*j/(7-i+j) \quad (3)$$

and, when i-j < 0, the diagonal convexity function is given according to Equation (4) as follows:

$$\text{diagconvex}(i,j) = 20/7 * i*(7-j)/(7+i-j) \quad (4)$$

Similarly, in one implementation, when i+j < 8, the cross-diagonal convexity function is given according to Equation (5) as follows:

$$\text{crossconvex}(i,j) = 20/7 * i*j/(i+j) \quad (5)$$

and, when i+j ≥ 8, the cross-diagonal convexity function is given according to Equation (6) as follows:

$$\text{crossconvex}(i,j) = 20/7 * (i-7)*(j-7)/(14-(i+j)) \quad (6)$$

In alternative implementations, the diagonal convexity function (diagconvex) and the cross-diagonal convexity function (crossconvex) can be other suitable adjustable convex functions.

The choice between the first parameterization of Equation (1) and the second parameterization of Equation (2) is dependent on the quality metric and the particular video test sequences. Other ways to parameterize a Q matrix are also possible.

The shape of a Q matrix, which is determined by the slope parameter (a), is updated using the DCT map information from the previously encoded frame that has the same picture type as the current frame. In general, the mapping from the DCT slope to the Q matrix slope is a decreasing function. In one implementation, the function for mapping from the DCT map slope (s) to the Q matrix slope (a) is given by Equation (7) as follows:

$$a = 0.5 + 1.5 * \exp(-s * \ln 3 / 3) \quad (7)$$

This function was obtained from an exhaustive search using a visual discrimination model as the distortion measure while the bit rate is being kept constant. In order to compute the slope (s) of the DCT map, the mean absolute value of the DCT coefficients for a given

frame is computed. The slope of the diagonal for the mean DCT map is then computed, e.g., either by a least squares fit for all of the diagonal elements or just the two end points. Note that the DCT map slope is computed from the DCT data of the previously encoded frame that has the same picture type as the current frame.

Q Matrix Mean Adjustment

When the bit budget is tight, spatial distortion (mostly caused by blockiness) is often more objectionable perceptually than frequency-domain distortion. This indicates that it is better to increase the Q matrix than the quantization scale (mquant), when the bit budget is scarce. It is generally true that the average quantization scale increases when the coding difficulty is higher, which means that the bit budget may not be high enough to guarantee the expected picture quality.

According to embodiments of the present invention, after performing the previously described shape adaptation, the mean of a Q matrix is adjusted to a target mean. The target mean is also updated frame by frame in order to adapt to the varying coding difficulty. The coding difficulty may be estimated as the product of the average mquant (M) and the target mean (C). In one possible implementation, the formula for adjusting the mean of the Q matrix is given by Equation (8) as follows:

$$Cnew = r * (Mold * Cold) / (Mref * Cref) * (Cref + (1-r) * Cref \qquad (8)$$

where:

Cnew is the adjusted target mean for the current frame;

r is a specified sensitivity parameter (e.g., 0.5);

Mold is the average mquant for the previously encoded frame of the same type;

Cold is the target mean for the previously encoded frame of the same type;

Mref is a specified default mquant for the current frame type; and

Cref is a specified default target mean for the current frame type.

The three specified parameters (r, Mref, and Cref) can be determined by an exhaustive search for a test sequence using a suitable perceptual quality metric. Note that Equation

(8) is applied with three potentially different sets of parameters for the three different frame types (I, P, and B). Typical values for these parameters are as follows:

For I frames, r=0.5, Mref=15, and Cref=45;

For P frames, r=0.5, Mref=15, and Cref=45; and

For B frames, r=0.5, Mref =17, and Cref=41.

Flow Diagram

Fig. 1 shows a flow diagram of processing for a current frame of video data, according to one embodiment of the present invention. Steps **102-108** correspond to the Q matrix shape adaptation part of the present invention, while step **110** corresponds to the Q matrix mean adjustment part.

In particular, in step **102**, the DCT map for the previously encoded frame of the same type as the current frame is generated based on the mean absolute values of the DCT coefficients for that previously encoded frame. The slope (s) of the diagonal of the DCT map for the previously encoded frame is then determined in step **104**, e.g., using a least squares fit of all of the elements along the diagonal or using just the end points of the diagonal. The slope (a) of the diagonal of the Q matrix for the current frame is then determined in step **106** based on the slope (s) of the diagonal of the DCT map, e.g., using Equation (7). The Q matrix for the current frame is then generated in step **108** based on the slope (a) of the Q matrix diagonal, e.g., using the parameterized function of Equation (1) or (2).

In step **110**, the Q matrix for the current frame is then optionally adjusted for changes in the target mean from the previously encoded frame of the same type, e.g., using Equation (8). In either case, in step **112**, the Q matrix for the current frame is then used to quantize the DCT coefficients for the current frame as the quantization step of the process of compressing the current frame for encoding into an encoded video bitstream.

Although Fig. 1 suggests that steps **102-104** are implemented during the processing of the current frame, in practice, it may be better (i.e., less memory required) to implement those steps as part of the processing of the previously encoded frame of the same type.

The present invention can be embodied in the form of methods and apparatuses for practicing those methods. The present invention can also be embodied in the form of program code embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other machine-readable storage medium, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of program code, for example, whether stored in a storage medium, loaded into and/or executed by a machine, or transmitted over some transmission medium or carrier, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. When implemented on a general-purpose processor, the program code segments combine with the processor to provide a unique device that operates analogously to specific logic circuits.

It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of this invention may be made by those skilled in the art without departing from the principle and scope of the invention as sexpressed in the following claims.

CLAIMS:

What is claimed is:

1. A method for processing a current frame of video data, comprising the steps of:

(a) generating a transform map for a previously encoded frame of video data of the same type as the current frame;

(b) generating one or more quantization (Q) matrix shape parameters using the transform map for the previously encoded frame;

(c) generating a Q matrix for the current frame using a parameterized function based on the one or more Q matrix shape parameters;

(d) quantizing transform coefficients corresponding to the current frame based on the Q matrix; and

(e) generating part of an encoded video bitstream based on the quantized transform coefficients.

2. The method of claim 1, wherein the previously encoded frame is the same type of video frame as the current frame.

3. The method of claim 1, wherein the transform map is a DCT map corresponding to mean absolute values of DCT coefficients for the previously encoded frame and the transform coefficients are DCT coefficients for the current frame.

4. The method of claim 1, wherein step (c) further comprises the step of adjusting the Q matrix for changes in target mean from the previously encoded frame to the current frame.

5. The method of claim 1, wherein:

the one or more shape parameters comprise a diagonal slope of the Q matrix; and

step (b) comprises the steps of:

(1) generating a diagonal slope of the transform map; and

(2) generating the diagonal slope of the Q matrix using a mapping function based on the diagonal slope of the transform map.

6. The method of claim 5, wherein the mapping function is based on an exhaustive search using a visual discrimination model.

7. The method of claim 1, wherein the parameterized function is a sinusoidal function.

8. The method of claim 1, wherein the parameterized function is a rational function.

9. The method of claim 1, wherein:

the previously encoded frame is the same type of video frame as the current frame;

the transform map is a DCT map corresponding to mean absolute values of DCT coefficients for the previously encoded frame and the transform coefficients are DCT coefficients for the current frame;

the one or more shape parameters comprise a diagonal slope of the Q matrix;

step (b) comprises the steps of:

(1) generating a diagonal slope of the transform map; and

(2) generating the diagonal slope of the Q matrix using a mapping function based on the diagonal slope of the transform map, wherein the mapping function is based on an exhaustive search using a visual discrimination model; and

step (c) further comprises the step of adjusting the Q matrix for changes in target mean from the previously encoded frame to the current frame.

10. A machine-readable medium, having encoded thereon program code, wherein, when the program code is executed by a machine, the machine implements a method for processing a current frame of video data, comprising the steps of:

(a) generating a transform map for a previously encoded frame of video data of the same type as the current frame;

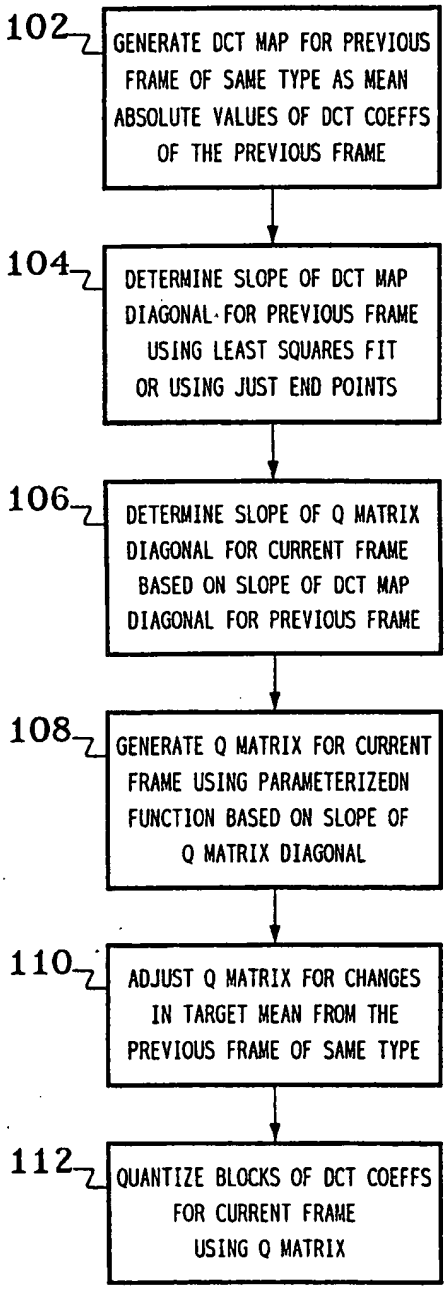
(b) generating one or more quantization (Q) matrix shape parameters using the transform map for the previously encoded frame;

(c) generating a Q matrix for the current frame using a parameterized function based on the one or more Q matrix shape parameters;

(d) quantizing transform coefficients corresponding to the current frame based on the Q matrix; and

(e) generating part of an encoded video bitstream based on the quantized transform coefficients.

FIG. 1


102
GENERATE DCT MAP FOR PREVIOUS FRAME OF SAME TYPE AS MEAN ABSOLUTE VALUES OF DCT COEFFS OF THE PREVIOUS FRAME
104
DETERMINE SLOPE OF DCT MAP DIAGONAL FOR PREVIOUS FRAME USING LEAST SQUARES FIT OR USING JUST END POINTS
106
DETERMINE SLOPE OF Q MATRIX DIAGONAL FOR CURRENT FRAME BASED ON SLOPE OF DCT MAP DIAGONAL FOR PREVIOUS FRAME
108
GENERATE Q MATRIX FOR CURRENT FRAME USING PARAMETERIZEDN FUNCTION BASED ON SLOPE OF Q MATRIX DIAGONAL
110
ADJUST Q MATRIX FOR CHANGES IN TARGET MEAN FROM THE PREVIOUS FRAME OF SAME TYPE
112
QUANTIZE BLOCKS OF DCT COEFFS FOR CURRENT FRAME USING Q MATRIX

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 1/66
US CL :375/240.2, 382/243, 382/251

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/240.2, 375/240.3, 238/243, 382/251

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,734,737 A (CHANG et al) 31 March 1998, col. 1, line 5 - col. 2, line 60.	1
A	US 5,717,465 A (KIM) 10 February 1998, col. 1, line 64 - col. 2, line 30.	1, 10
A	US 5,444,800 A (KIM) 22 August 1995, Abstract.	1, 10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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